United States
Department of
Agriculture

Forest Service

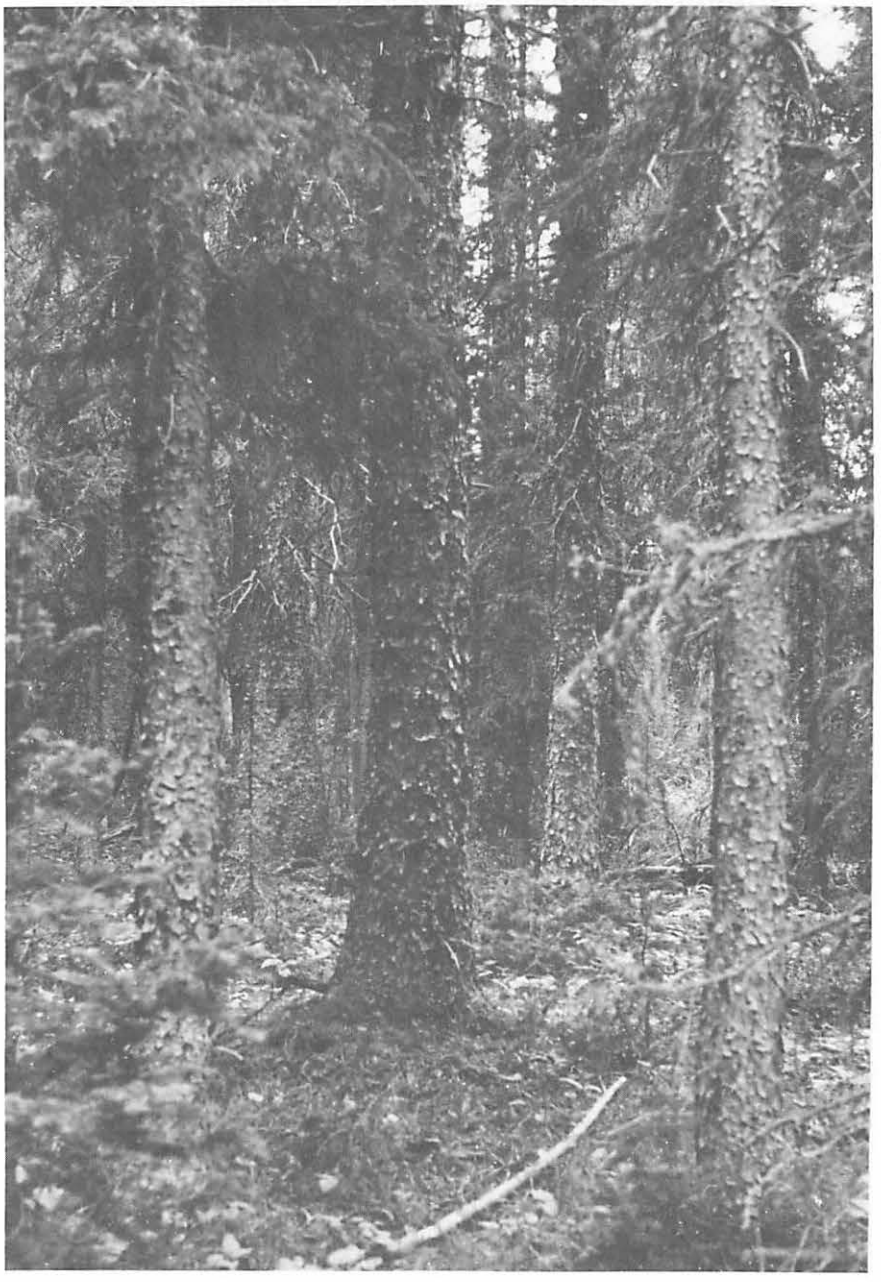
**Rocky Mountain
Forest and Range
Experiment Station**

Fort Collins,
Colorado 80526

**Research Paper
RM-269**

Estimating Potential Engelmann Spruce Seed Production on the Fraser Experimental Forest, Colorado

Robert R. Alexander, Carleton B. Edminster, and Ross K. Watkins



USDA Forest Service
Research Paper RM-269

July 1986

Estimating Potential Engelmann Spruce Seed Production on the Fraser Experimental Forest, Colorado

Robert R. Alexander, Chief Silviculturist
Carleton B. Edminster, Principal Mensurationist

and

Ross K. Watkins, Forestry Research Technician
Rocky Mountain Forest and Range Experiment Station[1]

Abstract

Two good, three heavy, and two bumper spruce seed crops were produced during a 15-year period. There was considerable variability in seed crops, however. Not all locations produced good to bumper seed crops when overall yearly ratings averaged good or better; conversely, some locations produced bumper seed crops in 3 or more years. Mathematical relationships, that should be useful in estimating potential sound seed production, were estimated between periodic annual 15-year sound seed production and (1) periodic annual 15-year total seed production and (2) selected stand parameters of dominant and codominant spruces.

Cover.—Engelmann spruce seed production study plot, Fraser Experimental Forest, Colorado.

[1]*Headquarters is in Fort Collins, in cooperation with Colorado State University.*

Estimating Potential Engelmann Spruce Seed Production on the Fraser Experimental Forest, Colorado

Robert R. Alexander, Carleton B. Edminster, and Ross K. Watkins

Management Implications

Knowledge of the frequency of good seed crops and the relationship of seed production to stand, tree, and/or crown characteristics is essential to the management of spruce-fir forests when relying on natural reproduction. Past studies have provided seed dispersal and seedling survival data that indicate sufficient viable seeds were produced in 7 out of 15 years of the current study to adequately restock all aspects under a group selection, individual-tree selection, or a shelterwood cutting alternative, provided that seedbed and environmental conditions were favorable.

Enough seeds were produced during the 15-year period to adequately regenerate clearcut openings, except on south aspects, if the openings were kept small enough (3- to 5-acre patches or strips no wider than 400 to 450 feet) to be within effective seed dispersal distances, and if seedbed and environmental conditions were favorable (Alexander 1986a, 1986b; Alexander and Edminster 1983). Clearcutting on south slopes is not likely to result in successful natural spruce regeneration regardless of the quantity of seed available, even with good seedbeds, because of unfavorable environmental conditions (Alexander 1983, 1984; Noble and Alexander 1977).

Equations developed to estimate potential seed production do not apply to stand conditions outside of the range of stand variables given in table 2.

Introduction

Prompt establishment of Engelmann spruce (*Picea engelmannii* Parry ex. Engelm.) natural reproduction after timber harvest is a major objective in the management of spruce-subalpine fir [*Abies lasiocarpa* (Hook.) Nutt.] forests in the central and southern Rocky Mountains (Alexander 1986a, 1986b). Good seedbed conditions and a favorable environment are necessary for natural reproduction; but they are of little value without an adequate seed supply (Alexander 1983, 1984; Noble and Alexander 1977; Roe et al. 1970). Infrequent good seed crops limit the potential for natural regeneration success and require either the use of cutting methods that provide a seed source on the site, or else artificial reforestation (Alexander 1986a, 1986b).

Past studies of Engelmann spruce seedfall in the central and southern Rocky Mountains indicated that intervals between years of good to bumper seed production are erratic, with more poor than good seed crops (Alexander 1969, Jones 1967, Noble and Ronco 1978). Similar results have been reported for spruce seed production elsewhere (Alexander 1986b, Alexander and Shepperd 1984).

A long-term study of spruce seed production, in high-elevation forests, in central Colorado, was started in 1968; plots were established by 1970. Five- and 10-year progress reports were published (Alexander and Noble 1976, Alexander et al. 1982). Those data are included here, along with the data for the years 1980 through 1984.

Study Areas

Thirteen permanent sample plots, 2-chains on a side, were established in old-growth spruce-fir forests on the Fraser Experimental Forest (Alexander et al. 1982, 1985). Plots covered a range of elevations, slopes, aspects, ages of dominant trees, and site productivity (table 1). All stands were in an *Abies lasiocarpa/Vaccinium scoparium* habitat type where the overstory was dominated by Engelmann spruce (Hess and Alexander 1986). Stand characteristics for each location are shown in table 2.

Methods

Seed Production

Seed production was estimated from seeds collected in ten 1-square-foot seed traps randomly located within each plot (fig. 1). Seed trap contents were collected one or more times each fall beginning in mid- to late September, weather conditions permitting, and again the following spring. All seeds were tested for soundness and recorded as (1) filled, or (2) partially filled or empty. Estimates of seed produced were based on counts of filled seed only.

Differences in seedfall for locations and years were tested by analysis of variance, with number of filled seeds per trap as the dependent variable. Variance of untransformed data by years was very heterogeneous. Univariate tests for homogeneity of variance for all years were significant ($p < 0.05$). The transformation of seed count data to $\sqrt{X + 3/8}$ reduced the variability to some degree; but 7 years of seed count data still had heterogeneous variance.

The following categories described by Alexander and Noble (1976) were used to rate the seed crops.

Filled seeds per acre	Seed crop rating
<10,000	Failure
10,000–50,000	Poor
50,000–100,000	Fair
100,000–250,000	Good
250,000–500,000	Heavy
>500,000	Bumper

The relationship between the amount of filled seed produced and total seedfall was examined by regression

Table 1.—Characteristics of plots in seed production study, Fraser Experimental Forest, Colorado.

Plot number	Location	Elevation	Aspect	Slope	Site index	Age of dominant trees at breast height	
						Mean	Range
		feet		*percent*		----- *years* -----	
1	Deadhorse Creek	9,140	N45°E	5	58	292	273-312
2	Deadhorse Creek	9,120	N45°E	5	68	280	240-304
3	Fool Creek	11,400	N25°E	5	42	250	236-266
4	Fool Creek	10,820	N10°W	12	61	247	238-264
5	Fool Creek	10,670	N10°E	15	50	242	233-251
6	Fool Creek	10,000	N25°E	12	65	246	236-261
7	W. St. Louis Creek	10,000	S50°E	25	70	289	277-298
8	W. St. Louis Creek	9,520	Due E	5	78	283	261-326
9	W. St. Louis Creek	9,560	Due N	30	64	291	283-299
10	Short Creek	9,400	N15°E	18	66	269	257-285
11	Short Creek	9,365	N50°W	13	77	246	231-252
12	Main St. Louis Creek	9,800	S20°E	5	55	284	263-309
13	E. St. Louis Creek	9,500	N10°W	5	82	192	173-204

Table 2.—Average stand characteristics, for dominant and codominant spruces, and total trees.

Plot number	Trees		Basal area		Diameter		Height		Live crown	
	Spruce	Total	Spruce	Total	Spruce	Total	Spruce	Total	Spruce	Total
	Number per acre		*Square feet per acre*		---- *Inches* ----		----- *Feet* -----		---- *Percent* ----	
1	64	319	84	150	15.6	9.4	79	50	74	68
2	54	249	102	176	19.2	11.8	90	58	67	66
3	88	220	139	196	17.4	12.9	62	47	72	70
4	100	320	195	306	19.1	13.4	81	59	64	61
5	95	525	94	258	13.7	9.6	68	50	62	54
6	63	345	104	197	17.5	10.3	87	55	64	60
7	65	365	107	205	17.4	10.1	88	52	71	65
8	58	286	116	193	19.3	12.0	95	59	63	62
9	90	278	105	183	14.8	10.9	85	63	55	55
10	43	283	61	145	16.6	10.1	87	54	66	65
11	35	213	72	141	19.9	11.2	100	56	74	70
12	63	293	80	182	15.6	10.8	81	57	71	67
13	74	205	150	206	19.7	13.8	99	68	66	65

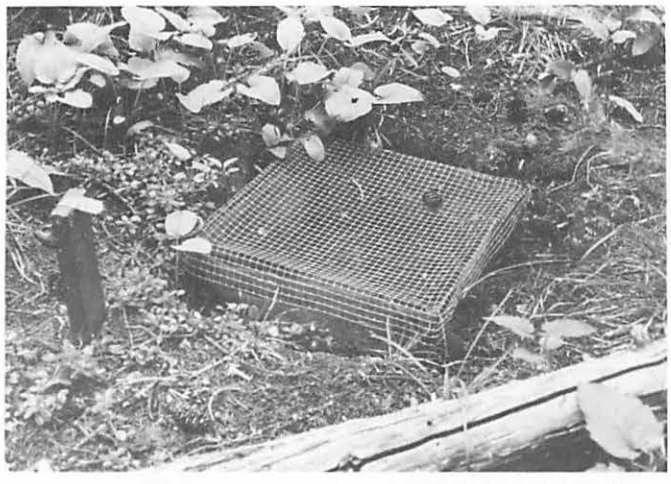


Figure 1.—One-foot-square wire seed trap in place. Fraser Experimental Forest, Colorado.

analysis, with the number of filled seeds per trap as the dependent variable.

Stand, Tree, and Crown Characteristics

Stand inventory information was collected as a basis for relating seed production to some measure of stand density, and/or tree and crown characteristics. Information obtained for individual trees on the plots included:

1. Diameter at breast height to the nearest 0.1 inch (trees 3.6 inches d.b.h. and larger).
2. Total height to the nearest 0.5 foot.
3. Crown class.
4. Species.
5. Average length of live crown to the nearest 0.5 foot (average of four sides).
6. Average width of live crown to nearest 0.1 foot (average of two measurements).

Ages of six to eight dominant spruces were measured for determination of site index (Alexander 1967).

These data were used to compute the following stand, tree, and crown parameters:

1. Number of trees per acre.
2. Basal area per acre.
3. Crown competition factor per acre.
4. Total crown volume per acre.
5. Total crown surface area per acre.
6. Average growing space per acre.
7. Average spacing per acre.
8. Average diameter.
9. Average height.
10. Average crown length.
11. Average crown width.
12. Average percent of live crown.
13. Average crown width/diameter ratio.
14. Average height/crown width ratio.
15. Average crown volume.
16. Average crown surface area.

Estimated average annual seed production for each location was plotted against individual and combinations of stand, tree, and crown measures. A stepwise regression program was then used to select the set of independent variables best correlated with seed production. Parameters based only on dominant and codominant spruces were used, because many studies have shown that coniferous species of these crown classes produce three-fourths or more of the seedfall (Fowells and Schubert 1956, Franklin et al. 1974).

Results and Discussion

Seed Production

Engelmann spruce seed was produced in larger quantities and at more frequent intervals (table 3) than previously measured on the Fraser Experimental Forest (Alexander 1969) and elsewhere in the central Rocky Mountains (Alexander 1986a, 1986b; Alexander and Shepperd 1984; Noble and Ronco 1978). Based on seed production averaged over all locations, crops were rated as shown for the 15 years of observations.

Seed crop rating	Number of years
Failure	2
Poor	4
Fair	2
Good	2
Heavy	3
Bumper	2

The quantity of seed produced varied from year to year. During the first 5 years of observation, good to heavy seed crops were produced in 4 out of 5 years. During the second 5 years, good to bumper crops were produced in 2 years; but, in the last 5 years, good to bumper crops were produced in only 1 year (fig. 2). Seed crops also varied considerably between locations. Not all locations produced good to bumper crops every good seed year, and some locations produced bumper crops in 3 or more years. Analysis of variance of the seed count

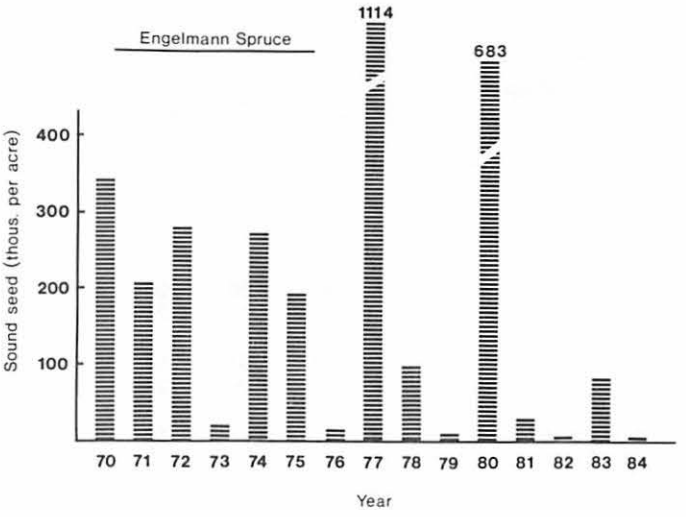


Figure 2.—Average annual Engelmann spruce seed production in relation to years.

data revealed that differences between years, between locations, and the interaction of years and locations were all highly significant ($p < 0.01$).

The amount of filled seed for each year at each location was significantly related to total seedfall, as shown in the following equation:

$$Y = 0.499X \quad [1]$$
$$R^2 = 0.87,\ S_{y.x} = 157{,}500$$

(coefficient of determination not centered about the mean—zero-intercept model)

where

Y = number of filled seeds per acre each year, and
X = number of total seeds per acre each year.

The equation, which accounts for more than 85% of total variation in sound seed production, shows that the number of filled seed produced increases linearly with total seedfall. The large standard error of estimate also indicates considerable variability in the relationship between filled and total seed production between years and locations.

Another significant finding in this study is that despite good or better seed production in 7 years, an average of only 46% (range 26% to 68%) of the total seedfall collected were filled in those years. Seed loss to insects, in particular to the spruce seed worm *(Cydia youngana)*, accounted for a large portion of the unsound, partially-filled seeds (Schmid et al. 1981).

The time of seedfall also varied between locations within any year, and between years at any location. The percentage of sound and total spruce seedfall, by collection dates, is shown in table 4 for those years of significant seed production when weather conditions permitted collections in both the fall and the following spring.

In 1971 and 1978, from 27% to 68% of the total sound seedfall was released by the end of September, while in 1972 and 1980 the percentage of sound seed released by the end of September varied from 0% to 60%. By the first week of October in 1972 and 1980, however, 36% to 80% of the sound seeds had been dispersed. In 1974, 1975,

Table 3.—Production of filled Engelmann spruce seeds (thousands per acre) and percent of total Engelmann spruce seedfall filled.

Crop	Plot number													
	1	2	3	4	5	6	7	8	9	10	11	12	13	Average
1970														
Filled seed	148	680	531	558	544	292	218	366	362	104	83	401	161	342
% of total	43	50	47	36	47	42	36	44	40	33	29	48	30	42
1971														
Filled seed	44	139	200	152	96	161	170	191	335	148	253	61	754	208
% of total	17	26	21	31	23	21	23	30	23	24	38	14	25	27
1972														
Filled seed	131	231	366	436	292	266	179	431	357	170	57	270	470	281
% of total	24	26	24	32	28	27	24	32	24	32	18	32	18	26
1973														
Filled seed	13	17	52	4	17	13	30	35	9	9	9	17	22	19
% of total	15	13	15	1	10	13	25	25	15	10	6	13	11	12
1974														
Filled seed	209	340	109	362	422	436	274	222	244	122	109	135	540	271
% of total	48	52	21	33	33	43	33	40	38	36	37	38	47	38
1975														
Filled seed	174	348	100	344	204	226	113	140	144	148	109	166	296	193
% of total	67	64	40	53	55	50	52	49	52	60	69	42	50	53
1976														
Filled seed	26	26	4	35	26	9	0	9	22	0	13	26	4	15
% of total	38	40	4	16	23	29	0	33	33	0	38	35	10	22
1977														
Filled seed	623	1,398	1,407	1,616	1,359	910	924	1,316	1,734	405	196	736	1,885	1,114
% of total	62	66	63	67	64	49	60	64	68	60	54	66	65	63
1978														
Filled seed	135	218	61	65	35	87	57	78	109	65	52	39	248	96
% of total	48	44	33	24	24	36	35	43	37	21	35	29	41	37
1979														
Filled seed	4	13	4	17	13	4	9	22	35	4	4	9	22	13
% of total	10	25	6	17	21	12	14	33	42	12	33	12	15	19
1980														
Filled seed	1,028	1,690	196	205	431	401	240	592	1,041	218	427	253	2,152	682
% of total	80	72	65	46	73	43	56	61	67	64	68	69	73	68
1981														
Filled seed	44	70	52	65	35	13	13	0	39	4	9	13	91	34
% of total	36	42	17	37	24	12	33	0	43	12	29	20	51	30
1982														
Filled seed	4	4	30	0	9	0	0	9	4	22	13	0	13	8
% of total	14	12	29	0	18	0	0	20	9	56	27	0	17	19
1983														
Filled seed	96	196	26	74	70	78	35	39	57	70	22	9	292	82
% of total	54	13	15	32	29	45	40	35	36	36	26	12	58	40
1984														
Filled seed	13	31	4	22	0	0	4	0	4	4	4	9	9	8
% of total	50	39	9	19	0	0	8	0	20	14	20	20	33	18
15-year average														
Filled seed	180	360	210	264	201	193	151	230	300	100	89	143	462	—
% of total	54	54	38	42	38	39	40	47	46	40	42	43	45	—

1977, and 1983, only nominal amounts of seed were released at most locations by the third week in September. In 1977, 60% to 80% of the sound seedfall had occurred by the first week in October; whereas, in 1974, 1975, and 1983, 39% to 100% of the sound seedfall occurred after the last fall collection was made in early October.

Relation of Seed Production to Stand and Tree Characteristics

Regression analyses of seed production and stand inventory variables resulted in the following equations:

$$Y = 5{,}395\ X^{0.796} \qquad [2]$$
$$S_{y.x} = 87{,}600$$

where

Y = periodic average annual sound spruce seed production per acre, and

X = basal area (square feet) of dominant and codominant spruces per acre.

$$Y = 5.936\ (X_1\ X_2)^{1.217} \qquad [3]$$
$$S_{y.x} = 84{,}000$$

where

Y = periodic average annual sound spruce seed production per acre,

Table 4.—Percent of total filled Engelmann spruce seeds released, by collection dates for years of significant Engelmann spruce seed production when collections could be made in the fall.[1]

Crop	Plot number												
	1	2	3	4	5	6	7	8	9	10	11	12	13
1971													
Sept. 27-28	40	53	65	63	55	49	44	32	42	47	38	64	68
June 6-21	60	47	35	37	45	51	56	68	58	53	62	36	32
1972													
Sept. 26-27	60	43	10	9	4	23	34	38	41	41	23	7	42
Oct. 10-11	7	28	32	48	40	22	27	22	21	28	23	29	19
June 18-July 3	33	29	58	43	56	55	39	40	38	31	54	64	39
1974													
Sept. 15-19	12	9	16	0	0	0	3	16	4	25	20	16	29
Oct. 2-3	41	31	12	26	29	45	40	21	39	36	32	23	32
June 24-July 10	46	60	72	74	71	55	57	63	57	39	48	61	39
1975													
Sept. 17-18	3	6	13	16	17	4	15	25	6	12	8	8	9
Oct. 6-7	42	36	4	15	6	25	12	16	15	38	20	37	31
June 9-July 1	55	58	83	69	77	71	73	59	79	50	72	55	60
1977													
Sept. 12-13	9	6	1	1	1	9	1	6	4	8	15	1	12
Oct. 3-4	55	65	60	66	65	71	71	69	68	60	57	59	61
June 22-July 12	36	29	39	33	34	20	28	25	28	32	27	40	27
1978													
Sept. 18-25	45	60	36	40	50	40	46	44	48	27	58	67	56
Oct. 10-11	16	6	36	13	0	20	23	22	32	33	17	22	11
June 27-July 16	39	34	28	47	50	40	31	34	20	40	25	11	33
1980													
Sept. 16-17	12	11	0	2	1	8	9	12	6	18	22	2	22
Oct. 6-7	48	50	42	53	80	57	40	46	53	36	37	67	48
June 2-30	40	39	58	45	39	35	51	42	41	46	41	31	30
1983													
Sept. 12-13	0	0	0	0	6	0	12	0	7	0	0	0	4
Sept. 26-29	18	2	0	0	6	17	13	0	23	6	0	0	18
July 7-16	82	98	100	100	88	83	75	100	70	94	100	100	78

[1]*No collections were made in the fall of 1970 because of early snowfall. Collections were made in the fall of 1973, 1976, 1979, 1981, 1982, 1983, and 1984, but seed production was negligible in those years.*

X_1 = average height (feet) of dominant and codominant spruces, and

X_2 = average number of stems of dominant and codominant spruces per acre.

The relationships to stand variables in both equations are weak; but no improvement was possible using other combinations of stand variables. However, the standard errors of estimate appear reasonable for this kind of data.

The average annual seed production was used as the dependent variable, because it is difficult to account for annual variation. Furthermore, the independent variables did not change significantly from year to year.

Conclusions

The precision of equations [2] and [3] may be about the best that can be expected for estimating periodic annual spruce seed production. However, the coefficients in these equations are likely to change over time. The 10-year mean seed production changed substantially from the 5-year mean (Alexander and Noble 1976) because of the 1977 seed crop; and the 15-year mean seed production changed from the 10-year mean (Alexander et al. 1982) because of the 1980 seed crop. While seed production from 1970 through 1984 was better than previous work had indicated, and the present study will be continued to provide more data, it is not likely that the amount of variation accounted for or the standard errors of estimate can be greatly improved.

The high correlation between annual seed fall and annual total seedfall (eq. [1]) is useful to managers, because they can expect the percentage of sound seeds to be higher in years when total seedfall is high. However, there is no clear indication of what influences the timing of seed production.

Equations [2] and [3] can be used for estimating potential periodic annual spruce seed production for large areas of stands with different characteristics over time. However, only about 35% to 40% of the variation is accounted for. While the standard errors of estimate appear reasonable for these kinds of data, they are very large. Therefore, the resolution between poor to heavy seed crops is not very good. The equations should not be applied to stand conditions outside the range of stand variables given in table 2.

These equations also do not provide the means for estimating the seed crop rating for any given location in an individual year. In some years, seed crops will be total failures; even in years of good overall seed produc-

tion, not all locations will produce good to bumper seed crops. Managers need a method of estimating seed crops from cone counts or some other visual means of estimating potential seed crops on a year-to-year basis.

In stands to be cut under selection or shelterwood methods, full- and long-crowned dominants and codominants should be retained as leave trees. These trees not only produce the most seed, but are also the most windfirm—an important consideration in partial cutting of high-elevation spruce forests. If trees are marked during a good seed year, it is possible to select the dominants and codominants with the largest number of cones. In years when seed crops are poor, old cones on the ground usually indicate which trees are likely to be the best seed producers.

Guidelines developed for partial cutting in old-growth spruce forests (Alexander 1986a) require more leave trees because of wind risk than the number needed for seed production. Furthermore, windfall susceptibility of trees and stands is more important than spacing of trees for seed production. If the leave trees blow down, the nearby seed source is lost.

In managed stands, the number of trees left at the time of the seed cut under a shelterwood method will vary from 20 to 45 dominants and codominants per acre, depending upon the number of entries, length of rotation, and site productivity for those growing stock levels that maximize timber production (Alexander and Edminster 1980). This should be an adequate seed source for natural regeneration if seedbeds are properly prepared and environmental conditions are favorable; but adequate restocking may require more than one good or better seed year when fewer seed trees are left.

Further work on this study is expected to provide more information on (1) the quantity of seed produced and frequency of good to heavy seed crops, and (2) the relationship of filled seed production to stand, tree, and crown parameters.

Literature Cited

Alexander, Robert R. 1967. Site indexes for Engelmann spruce in the central Rocky Mountains. USDA Forest Service Research Paper RM–32, 7 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Alexander, Robert R. 1969. Seedfall and establishment of Engelmann spruce in clearcut openings: A case history. USDA Forest Service Research Paper RM–53, 8 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Alexander, Robert R. 1983. Seed:seedling ratios of Engelmann spruce after clearcutting in the central Rocky Mountains. USDA Forest Service Research Note RM–246, 6 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Alexander, Robert R. 1984. Natural regeneration of Engelmann spruce after clearcutting in the central Rocky Mountains in relation to environmental factors. USDA Forest Service Research Paper RM–254, 17 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Alexander, Robert R. 1986a. Silvicultural systems and cutting methods for old-growth spruce-fir forests in the central and southern Rocky Mountains. USDA Forest Service General Technical Report RM–126, 33 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Alexander, Robert R. 1986b. Ecology, silviculture, and management of the Engelmann spruce-subalpine fir type in the central and southern Rocky Mountains. U.S. Department of Agriculture, Forest Service, Agricultural Handbook. Washington, D.C. (In press.)

Alexander, Robert R., and Carleton B. Edminster. 1980. Management of spruce-fir in even-aged stands in the central Rocky Mountains. USDA Forest Service Research Paper RM–217, 14 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Alexander, Robert R., and Carleton B. Edminster. 1983. Engelmann spruce seed dispersal in the central Rocky Mountains. USDA Forest Service Research Note RM–424, 4 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Alexander, Robert R., and Daniel L. Noble. 1976. Production of Engelmann spruce seed, Fraser Experimental Forest, Colorado: A 5-year progress report. USDA Forest Service Research Note RM–324, 4 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Alexander, Robert R., and Wayne D. Shepperd. 1984. Silvical characteristics of Engelmann spruce. USDA Forest Service General Technical Report RM–114, 38 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Alexander, Robert R., Charles A. Troendle, Merrill R. Kaufmann, Wayne D. Shepperd, Glenn L. Crouch, and Ross K. Watkins. 1985. The Fraser Experimental Forest, Colorado: Research program and published research 1937–1985. USDA Forest Service General Technical Report RM–118, 46 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Alexander, Robert R., Ross K. Watkins, and Carleton B. Edminster. 1982. Engelmann spruce seed production on the Fraser Experimental Forest, Colorado. USDA Forest Service Research Note RM–419, 6 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Fowells, H. A., and G. H. Schubert. 1956. Seed crops of forest trees in the pine region of California. U.S. Department of Agriculture Technical Bulletin 1150, 48 p. Washington, D.C.

Franklin, Jerry F., Richard Carkin, and Jack Booth. 1974. Seeding habits of upper-slope tree species. *In* A 12-year record of cone production. USDA Forest Service Research Note PNW–213, 12 p. Pacific Northwest Forest and Range Experiment Station, Portland, Oreg.

Hess, Karl, and Robert R. Alexander. 1986. Forest vegetation of the Arapaho and Roosevelt National Forests in central Colorado: A habitat type classification. USDA Forest Service Research Paper RM–266, 48 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Jones, John R. 1967. Regeneration of mixed conifer clearcuttings on the Apache National Forest, Arizona. USDA Forest Service Research Note RM–79, 8 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Noble, Daniel L., and Robert R. Alexander. 1977. Environmental factors affecting natural regeneration of Engelmann spruce in the central Rocky Mountains. Forest Science 23:420–429.

Noble, Daniel L., and Frank Ronco. 1978. Seedfall and the establishment of Engelmann spruce and subalpine fir in clearcut openings in Colorado. USDA Forest Service Research Paper RM–200, 12 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Roe, Arthur L., Robert R. Alexander, and Milton D. Andrews. 1970. Engelmann spruce regeneration practices in the Rocky Mountains. U.S. Department of Agriculture Production Research Report 115, 32 p. Washington, D.C.

Schmid, J. M., James C. Mitchell, and Robert E. Stevens. 1981. *Cydia youngana* (Kearfott) *(Lepidoptera:Tortricide)* and associates in Engelmann spruce cones, Fraser Experimental Forest, Colorado, 1974–1977. USDA Forest Service Research Note RM–394, 5 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Alexander, Robert R., Carleton B. Edminster, and Ross K. Watkins. 1986. Estimating potential Engelmann spruce seed production on the Fraser Experimental Forest, Colorado. USDA Forest Service Research Paper RM–269, 7 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Two good, three heavy, and two bumper spruce seed crops were produced during a 15-year period. There was considerable variability in seed crops, however. Not all locations produced good to bumper seed crops when overall yearly ratings averaged good or better; conversely, some locations produced bumper seed crops in 3 or more years. Mathematical relationships, that should be useful in estimating potential sound seed production, were estimated between periodic annual 15-year sound seed production and (1) periodic annual 15-year total seed production and (2) selected stand parameters of dominant and codominant spruces.

Key words: *Picea engelmannii*, seed production, natural regeneration

Alexander, Robert R., Carleton B. Edminster, and Ross K. Watkins. 1986. Estimating potential Engelmann spruce seed production on the Fraser Experimental Forest, Colorado. USDA Forest Service Research Paper RM–269, 7 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Two good, three heavy, and two bumper spruce seed crops were produced during a 15-year period. There was considerable variability in seed crops, however. Not all locations produced good to bumper seed crops when overall yearly ratings averaged good or better; conversely, some locations produced bumper seed crops in 3 or more years. Mathematical relationships, that should be useful in estimating potential sound seed production, were estimated between periodic annual 15-year sound seed production and (1) periodic annual 15-year total seed production and (2) selected stand parameters of dominant and codominant spruces.

Key words: *Picea engelmannii*, seed production, natural regeneration

Alexander, Robert R., Carleton B. Edminster, and Ross K. Watkins. 1986. Estimating potential Engelmann spruce seed production on the Fraser Experimental Forest, Colorado. USDA Forest Service Research Paper RM–269, 7 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Two good, three heavy, and two bumper spruce seed crops were produced during a 15-year period. There was considerable variability in seed crops, however. Not all locations produced good to bumper seed crops when overall yearly ratings averaged good or better; conversely, some locations produced bumper seed crops in 3 or more years. Mathematical relationships, that should be useful in estimating potential sound seed production, were estimated between periodic annual 15-year sound seed production and (1) periodic annual 15-year total seed production and (2) selected stand parameters of dominant and codominant spruces.

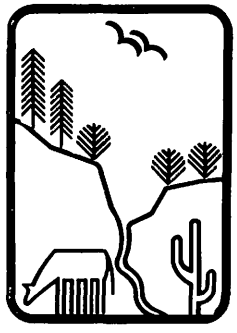
Key words: *Picea engelmannii*, seed production, natural regeneration

Alexander, Robert R., Carleton B. Edminster, and Ross K. Watkins. 1986. Estimating potential Engelmann spruce seed production on the Fraser Experimental Forest, Colorado. USDA Forest Service Research Paper RM–269, 7 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

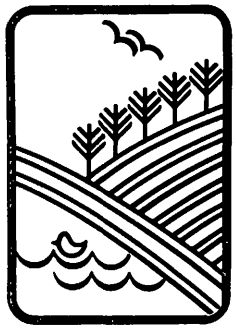
Two good, three heavy, and two bumper spruce seed crops were produced during a 15-year period. There was considerable variability in seed crops, however. Not all locations produced good to bumper seed crops when overall yearly ratings averaged good or better; conversely, some locations produced bumper seed crops in 3 or more years. Mathematical relationships, that should be useful in estimating potential sound seed production, were estimated between periodic annual 15-year sound seed production and (1) periodic annual 15-year total seed production and (2) selected stand parameters of dominant and codominant spruces.

Key words: *Picea engelmannii*, seed production, natural regeneration

Rocky Mountains



Southwest



Great Plains

U.S. Department of Agriculture
Forest Service

Rocky Mountain Forest and Range Experiment Station

The Rocky Mountain Station is one of eight regional experiment stations, plus the Forest Products Laboratory and the Washington Office Staff, that make up the Forest Service research organization.

RESEARCH FOCUS

Research programs at the Rocky Mountain Station are coordinated with area universities and with other institutions. Many studies are conducted on a cooperative basis to accelerate solutions to problems involving range, water, wildlife and fish habitat, human and community development, timber, recreation, protection, and multiresource evaluation.

RESEARCH LOCATIONS

Research Work Units of the Rocky Mountain Station are operated in cooperation with universities in the following cities:

Albuquerque, New Mexico
Flagstaff, Arizona
Fort Collins, Colorado*
Laramie, Wyoming
Lincoln, Nebraska
Rapid City, South Dakota
Tempe, Arizona

*Station Headquarters: 240 W. Prospect St., Fort Collins, CO 80526